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Engineering Specification

D4A (MBRA), D4B (MBRB) – DIPOLE COOLING SCHEME

Abstract

Superconducting beam separation dipoles of four different types are required in the Experimental Insertions (IR 1, 2, 5, and 8) and the RF Insertion (IR 4). The D4 twin aperture dipoles are among those utilized in the RF insertions. The D4 dipoles are cooled at 1.9 K. This specification establishes the requirements and interfaces for the cooling of the D4 dipoles.

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History of Changes

Rev. No.	Date	Pages	Description of Changes
0.1			First Draft
0.2	20001-02-20		Revised field lengths and heat loads using 30Jan01 version of Rob's tables. Updated text.

Table of Contents

1. OVERVIEW

D4 magnets, along with D3 magnets, are used at IR4 to increase the separation of the beams of the LHC from the nominal spacing of 194 mm to 420 mm so that individual RF cavities can be installed for each beam. The beams are then returned to the nominal 194 mm spacing [1].

The D4 magnet is a two-in-one magnet, having two coils in one cold mass similar to the LHC arc magnets [2]. The complete D4 consists of two 10 meter magnets, D4a (MBRA) and D4b (MBRB). These two magnets differ primarily in the separations of the beam tubes (232 mm for D4a and 194 mm for D4b). The D4 cold mass has an elliptical cross section with dimensions similar to that of an LHC arc magnet [3]. The D4 cryo-assembly designations are listed in Table 1.

Table 1. Hardware designations for D4a and D4b magnets

	D4a (232 mm)	***D4b (194 mm)***
Magnet designation	MBRA	MBRB
Cryo-assembly designation		
IR4L	LBRAA	LBRBA
IR4R	LBRAB	LBRBB

1.1 LOCATION

The D4 magnets are installed in IR4 between the Q7 magnet and the DFB feed box. A sketch of the left side of this region is shown in Figure 1. Dispersion suppressor magnets are located on the other side of Q7. The DS magnets are operated at 1.9 K and their superconducting buses are routed through the Q7 and D4 cryo-assemblies to the DFB feedbox. The D4-Q7-DS combination is treated as a single cryogenic module. Each magnet operates at 1.9 K, even though the D4 can provide the required field strength for the LHC when operated at 4.5 K.

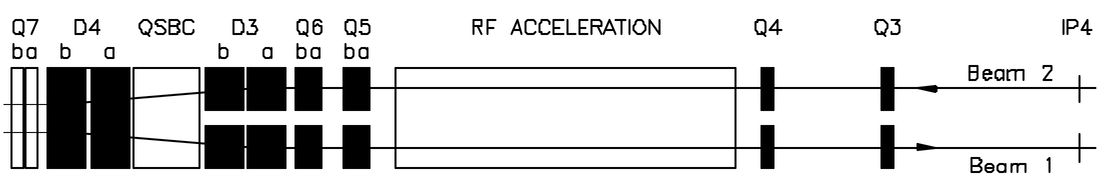


Figure 1. Geometry in the RF Region of the LHC. The nominal 194 mm separation of the beams is increased to 420 mm so that there is space for independent RF acceleration cavities for the two beams.

1.2 COOLING

The cooling scheme and cryostat design of the LHC arc magnets were adopted for D4 [4]. A 60 mm opening in the iron yoke contains a 58 mm copper heat exchanger tube used to provide the 1.9 K cooling. The magnet cold mass is immersed in a bath of helium II at 1 bar. The heat exchanger tube is connected to the LHC cryogenic distribution Header B and is kept at 0.016 bar. Two phase helium inside the exchanger tube flows downward for flow stability from the high elevation of the D4-Q7-DS module to the low end.

As in the LHC arc region, beam screens are used to shield the dynamic heat load from entering the 1.9 K magnets. Since the diameter for the D4 beam tube is larger than that of an LHC arc magnet, a larger beam screen is used. This screen is provided and installed by CERN.

Combining the D4, Q7 and DS magnets in the same cryogenic module simplifies the cryogenic interfaces. The 1.9 K and the heat shield systems are cooled in series. However, the D4 and Q7 beam screens are cooled in series with each other and in parallel with the DS beam screens.

2. CRYOSTAT LAYOUT

The cross sectional view of the LBRA/LBRB cryo-assemblies is shown in Figure 2. Each cold mass is enclosed in an aluminum heat shield and supported by three fiberglass-posts. The vacuum vessel and the posts are identical to those used in the LHC arc dipole magnets. Outside of the cold mass there are five cold pipes, identified as:

- C' – the small beam screen supply line.
- Two E – pipes for the heat shield.
- Two N – pipes to carry the superconducting bus from the DS magnets.

Only one of the E and N lines will be used in each location, the redundant arrangement allows the interchange of magnets between the left and the right sides of IR4.

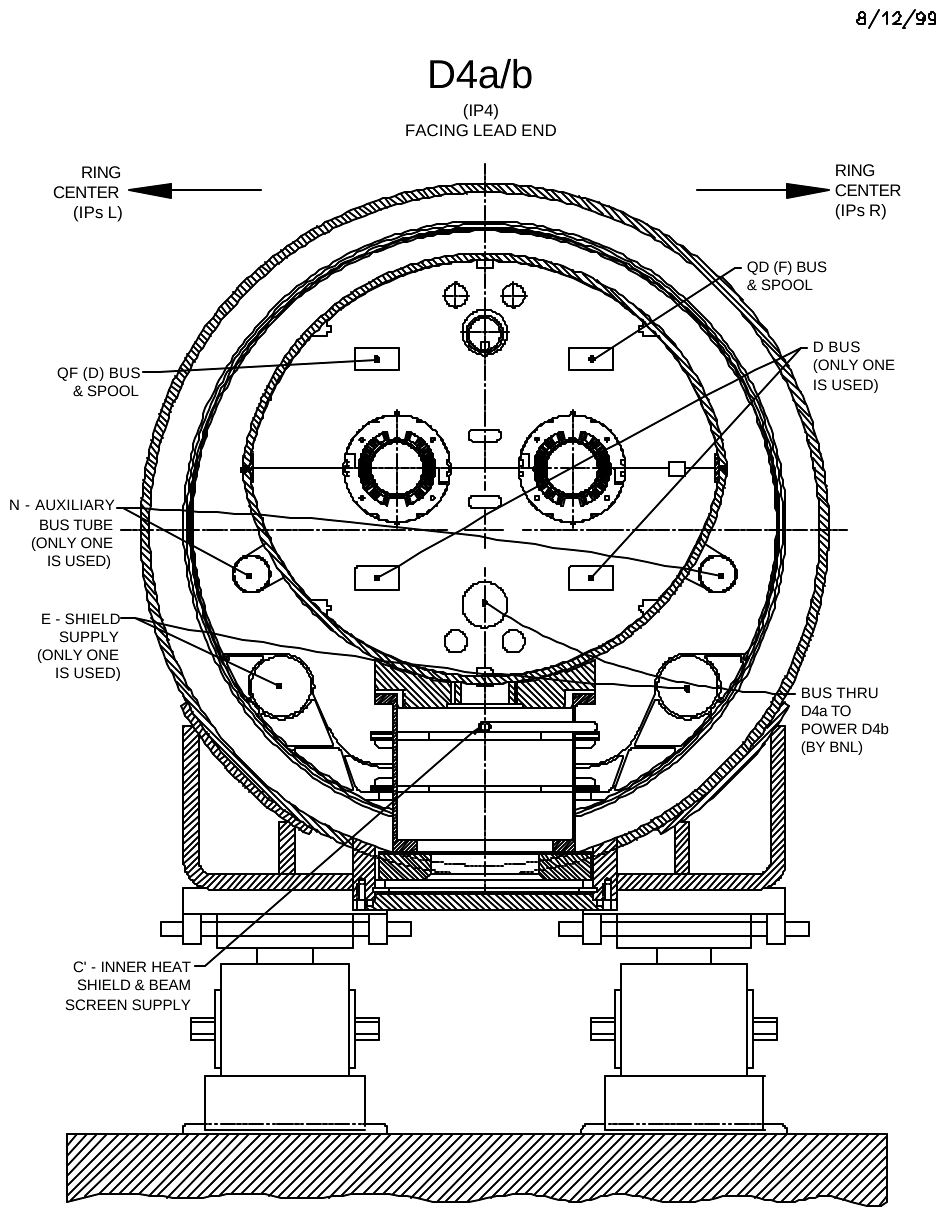


Figure 2 Sectional view of the LBRA/LBRB (D4a/D4b) cryo-assembly

3. COOLING

3.1 GENERAL REQUIREMENTS

Heat load is a key parameter for a cooling system. In the LHC, the heat loads consist of two types, static and dynamic. The static heat load comes from conduction through the supports, and radiation past the thermal insulation of the cryostat. The dynamic heat load comes from machine operation. The dynamic heat load consists of synchrotron radiation, imagine currents, beam scattering and photoelectron effects. The beam screen, operated between 4.5 and 20 K, is used to prevent the majority of the dynamic heat loads from entering the 1.9 K magnet. There are three temperature levels of heat load for D4: 50-75 K of the thermal heat shield, 4.5-20 K of the beam screen and 1.9 K of the magnet cold mass.

3.1.1 STATIC HEAT LOADS

Static heat load of D4 is estimated by R. van Weelderen of CERN [5] and is given in Table 2. Heat loads for electrical splices, instrumentation feed throughs and cryogenic jumper lines are also included in Table 2.

Table 2. Design Static heat load for a D4a or D4b magnet

Source	***Heat Shield*** ***50-75 K***	***Beam Screen*** ***4.5-20 K***	***Cold Mass*** ***1.9 K***
Supports	21.30	1.35	0.15
Thermal Shield (50-75 K)	27.95	-	-
Radiation to cold mass	-	-	1.01
Resistive heating (splices)	0.01	0.02	0.29
Instrument feed through	-	-	0.53
½ jumper	0	0.01	0.03
Total	49.26	1.38	2.01

3.1.2 DYNAMIC HEAT LOADS

The dynamic heat load is developed inside the beam tube. It does not reach the 50-75 K heat shield. An actively cooled beam screen is used to remove most of the dynamic heat loads that would otherwise be deposited in the 1.9 K magnet. The dynamic heat loads of D4 are estimated by CERN [5] for both the nominal and ultimate LHC operating conditions, and are given in Table 3. The heat loads for synchrotron radiation, image currents, beam scattering and photoelectrons are given in watts per meter. The photoelectron heat input depends on whether or not the region has magnetic field present. The length used in Table 3 is 10.35 m and includes the interconnecting piping. The field free region is 0.90 m.

Table 3. Dynamic heat load of D4 at nominal and ulitmate operating conditions

Source	Beam Screen Nominal	Cold Mass Nominal	Beam Screen Ultimate	Cold Mass Ultimate
Synchrotron radiation (W/m)	0.200	0	0.302	0
Image Current (W/m)	0.178	0.005	0.407	0.010
Beam gas scattering (W/m)	0	0.050	0	0.050
Resistive heating-splices (W/m)	-	-	-	-
Photoelectron[a]				
-field region (W/m)	0.241	0	0.830	0
-field free region (W/m)	2.079	0	7.140	0
Total for 10.35 meter length[a]	8.06	0.57	21.61	0.62

Note: (a) From the mechanical layout drawings [6], the field region is taken as the magnetic length 9.45m. The total length is taken as the cold mass length 10.35 m. Their difference is taken as the field free region 0.90 m.

3.1.3 TOTAL HEAT LOADS

Total heat load is the sum of static and dynamic heat load and is given in Table 4. The cooling system must be designed for the maximum heat load of the D4 cryogenic module with a safety margin as shown in Table 5. Pressure and temperature at the 4.5 K supply line shall be 3 bar and 4.6 K. Pressure in the return line D is not expected to be greater than 1.3 bar during normal operation.

Table 4. Total heat load (Watts) for the D4 magnets at nominal and ultimate luminosity

	Heat Shield 50-75 K	Beam Screen 4.5-20 K	Cold Mass 1.9 K
Nominal			
Static (Table 1)	49.3	1.4	2.0
Dynamic (Table 2)	0	8.1	0.6
Total	49.3	9.5	2.6
Ultimate			
Static (Table 1)	49.3	1.4	2.0
Dynamic (Table 2)	0	21.6	0.6
Total	49.3	23.0	2.6

Table 5. Total heat load for the combined D4a-D4b cryogenic module

	Heat Shield	***Beam Screen***	***Cold Mass***
	50-75 K	***4.5-20 K***	***1.9 K***
Nominal	98.6	19.0	5.2
Ultimate	98.6	46.0	5.2
Design value for cooling system	230	60	20

3.2 COOLING SCHEME

The D4-Q7-DS module is connected to both the LHC distribution system and the neighboring cryogenic module. In the left side of IR 4, the connection point to the LHC distribution line is in the D4a side. In the right side of IR 4, the connection point is at the end of the DS.

The 1.9 K cooling for D4 and Q7 is connected in series with the DS magnets. The magnet leads of D4 face the DFB. The shield system of the D4-Q7-DS module is in series with that of other LHC magnets in the half sector. However, the beam screen cooling lines for D4 and Q7 are in parallel with those of the DS magnets to minimize pressure drop. The flow schematics for D4 in the left and right side of IR4 are given in Figures 3 and 4. The dashed box indicates the responsibility of BNL.

3.3 1.9 K OPERATION

In each side of IR4, the 1.9 K cooling for D4-Q7 is in series with the DS magnets. The 1.9 K supply line is connected to Header C in the low elevation end of the D4-Q7-DS module. After passing through the 4.5 – 1.9 K heat exchanger HX, helium flows through TCV100 to feed the cryogenic module. A small tube inside the 1.9 K cooling tube is used to transport helium to the high elevation end. This permits the two phase helium to flow downward to provide stable cooling. The low pressure helium returns to Header B through the 4.5 K – 1.9 K HX.

3.4 HEAT SHIELD COOLING

Heat shield cooling is provided by helium from the IP side to the center of the sector. Helium flows from the DFB, through the E line in D4-Q7-DS module, to the entire half sector. The temperature control valve is located in the end of the half sector. The flow schematics in the left and the right side of IR 4 are given in Figure 3 and 4.

3.5 COOLDOWN FROM 300 - 4.5 K

In the left side of IR 4, the cooldown line is connected from Header C to D4a as shown in Figure 3. When CFV200 opens, helium flows to cool D4a, D4b, Q7 and the DS cell. Helium returns through SRV200, in the end of the DS magnet, to Header D.

In the right side of IR 4, the cooldown line is connected from Header C to the end of the DS magnet as shown in Figure 4. When CFV200 opens, helium flows to cool the DS cell, Q7, D4b and D4a. Helium returns through SRV200, in the end of D4a, to Header D.

The temperature difference between the cooling helium and the magnet shall be kept below 50 K.

3.6 BEAM SCREEN COOLING

The beam screen cooling helium, flowing from Header C through the C' line, enters the low elevation end of the cryogenic module. It exits the high elevation end and returns to Header D. Two temperature control valves, TCV2, are used to maintain each screen below 20 K.

In each side of IR 4, the beam screen cooling is divided into three parallel circuits to minimize pressure drop. The beam screen supply is connected to Header C. Helium flows through the C' line to feed the beam screen in the far end of the circuit. After providing cooling to the beam screen, helium returns to Header D. Valves TCV400s are used to control the screen temperature. Both the supply and the return connections are in the same location.

In the left side of IR 4, the beam screens for D4a, D4b and Q7 are connected in series and helium is fed from D4a. The beam screens in the DS magnet are equally divided into two circuits and helium is fed from each end of DS.

In the right side of IR 4, the beam screens for D4a and D4b are connected in series and helium is fed from D4a. The beam screen for Q7 is connected with that of the DS magnet. Helium is fed from Q7 and the end of DS respectively for the two circuits. The configuration is chosen based on the location available for connecting to the LHC distribution line.

3.7 SAFETY RELIEF VALVE

In each side of IR 4, two safety relief valves SRV200 and SRV210 are installed in the D4-Q7-DS module for releasing helium to the D Header should pressure in the module exceeds the design value. The 50-75 K cooling of D3 is part of the LHC Sector heat shield which has relief valves to handle the venting capacity of the entire circuit. There is no valve between the beam screen and Header C in the LHC distribution line. The relief valve in Header C can be used to vent helium in the 4.5-20 K cooling line. There is no valve between the D3 cold mass and Header D either. Two phase helium in the D3 cold mass will be vented to the Header D should there is a pressure build up. No relief valve is allocated for the D4 cryogenic module. However, vacuum tank relief will be provided on each D4a and D4b cryostat.

3.8 SUPERCONDUCTING BUS FOR DS MAGNETS

The superconducting bus for the DS magnets are routed from the DFB feed box located in the IP side of the module. The bus is installed inside the N line attached on the surface of the cold mass and has the same length as the cryogenic module. During LHC operation, the N line is maintained at 1.9 K by connecting it with the single phase helium II in the magnets in a few locations. There is no connection between the N line and helium inside the D4 magnets. In this region the N line is cooled by conduction to the D4 cold mass.

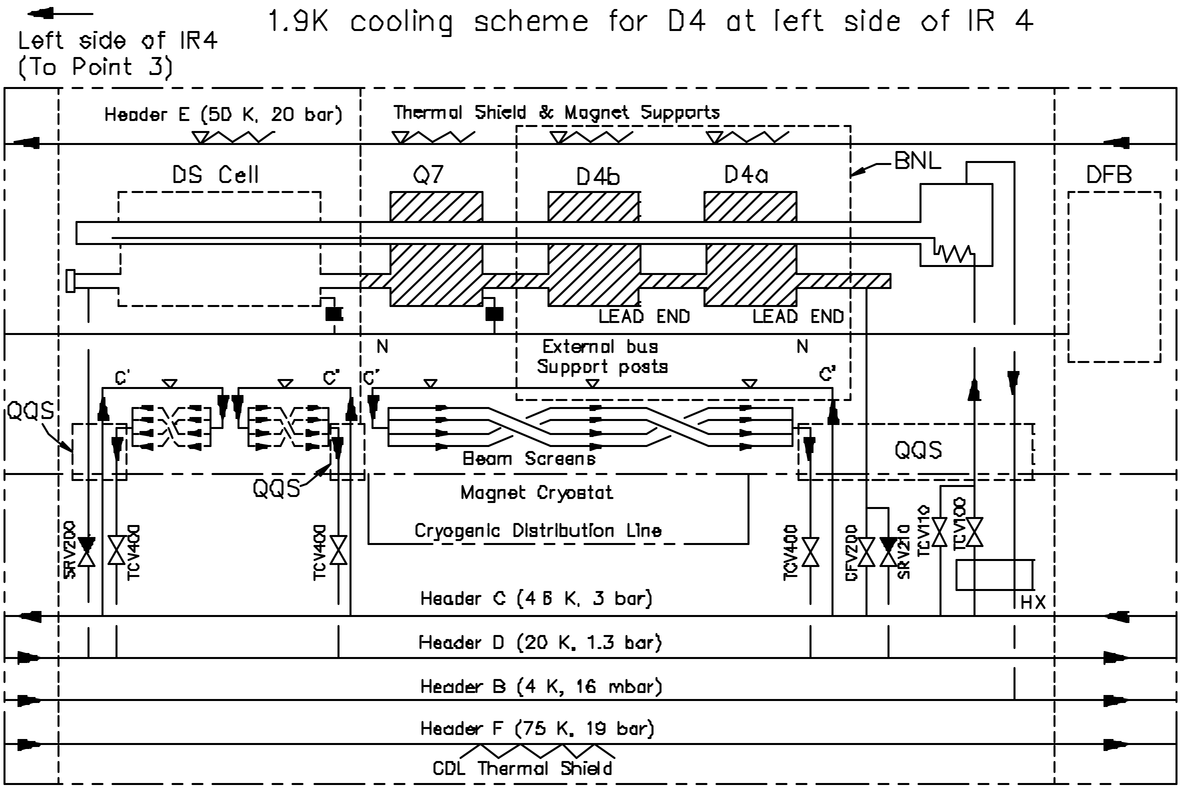
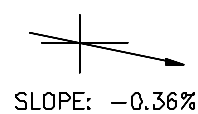


Figure 3 1.9 K cooling scheme for D4 at the left side of IR 4



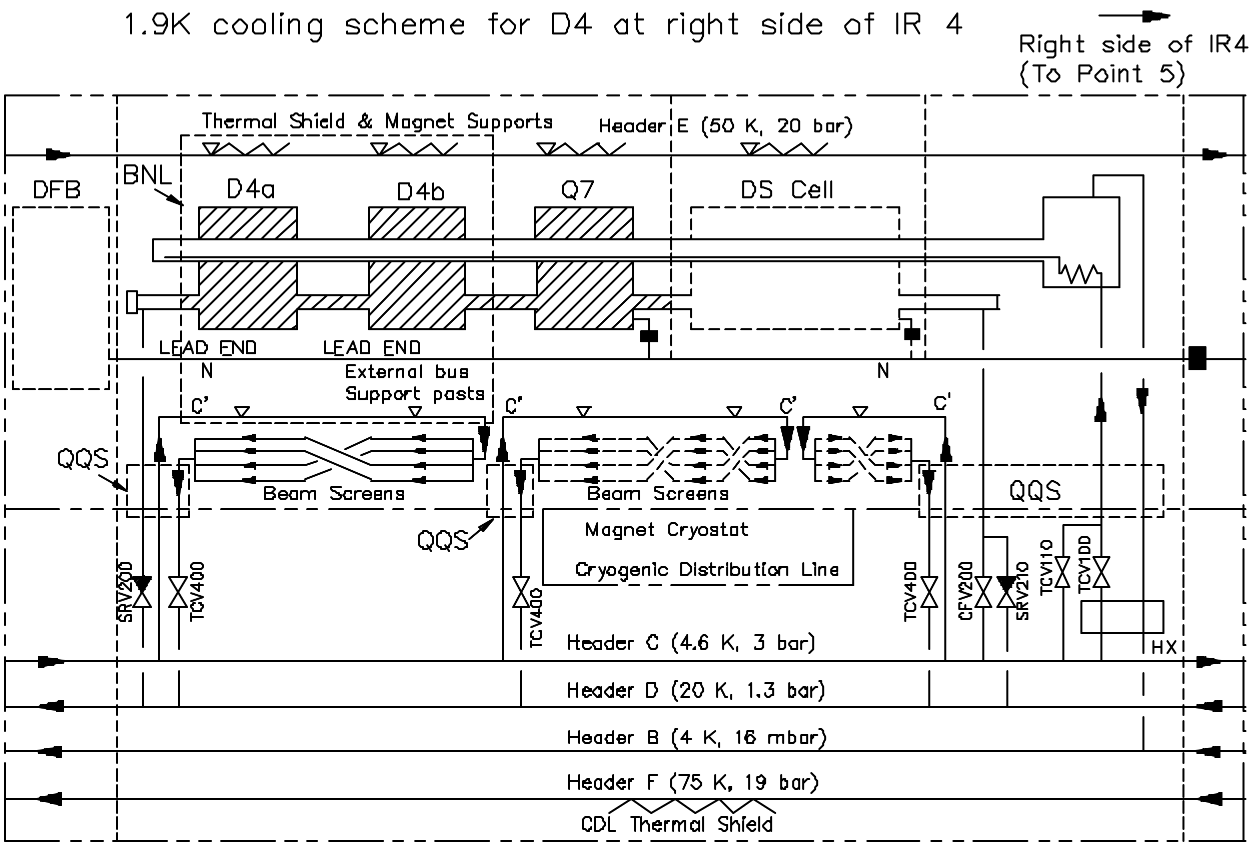
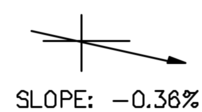


Figure 4 1.9 K cooling scheme for D4 on the right side of IR 4



4. REFERENCES

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